Research Article

Rusul Abdul Rahim Ghadban and Mohammed Ali Abdulrehman*

Study of some properties of colored geopolymer concrete consisting of slag

https://doi.org/10.1515/jmbm-2022-0066
received April 12, 2022; accepted April 29, 2022

Abstract: In this study, the possibility of producing colored geopolymer concrete consisting of slag as a binder and studying the effect of pigment on some properties of geopolymer concrete is discussed. Here two types of pigments (chromium oxide "green" and iron oxide hydroxide "yellow") were added to the geopolymer concrete and some tests such as slump values, compressive strength, flexural strength, and permeability test were conducted. The results showed that the best percentage of pigment addition was 1% of the weight of the slag, and with increasing addition, the mechanical properties began to deteriorate.

Keywords: geopolymer concrete, colored concrete, slag, pigment

1 Introduction

The word "geopolymer" was used by Davidovits in 1978 to describe a wide range of materials defined by inorganic molecular networks [1]. The mineral sources of silicon (Si) and aluminum (Al) in geopolymer concrete include thermally active natural sources such as metakaolin or industrial byproducts such as fly ash or slag. These two waste materials can be dissolved in alkaline activating solutions, which then polymerize them into molecular chains and turn them into a binder. Ranjan explained that "the polymerization process entails a very rapid chemical reaction of alkaline conditions of silicon and aluminum metals, resulting in a three-dimensional polymeric chain and ring structure." Geopolymer concrete has exceptional properties such as its cohesion at room temperature, non-toxic, impermeable, better heat resistance, and resistance to all inorganic solvents, and these properties have motivated researchers to consider the idea of using it in structural parts [2].

There are many researchers who have provided studies on slag when it is used in the production of geopolymer concrete. Bernal *et al.* had examined the mechanical and durability properties of concrete made from blast furnace slag with alkali silicate activated as the binding material [3]. Srinivasan *et al.* had studied the complete replacement of cement with ground granulated blast furnace slag [4]. Turkmen *et al.* had investigated the influence of varied sodium hydroxide (NaOH) concentrations and curing temperatures on the mechanical characteristics of Elaz ferrochrome slag-based geopolymer pastes [5].

Colored concrete is produced by adding pigment to the concrete components while mixing the concrete components. Pigments produced specifically for concrete are available in both synthetic and natural forms and are designed to obtain sufficient color without completely affecting the desired physical properties of the mixture [6]. Many researchers who have studied colored concrete like Lee HS *et al.* had investigated the effects of Fe_2O_3 pigments on the properties of concrete interlocking blocks [7]. Karaguler and Sungur had studied the effects of adding five types of inorganic pigments (red, black, green, yellow, and ultramarine blue) to architectural self-compacting concrete [8]. Mahmud and Abdulrehman had investigated the mechanical and physical characteristics of colored geopolymer concrete by incorporating two types of pigments, blue (cobalt) and yellow (iron oxide hydroxide) [9]. This study aims to produce colored concrete that is more environmental friendly by coloring slag-based geopolymer concrete.

2 Materials and laboratory parts

2.1 Materials

2.1.1 Slag

The slag used in this study is available in the Iraqi market and imported from Turkey. The chemical composition of

* **Corresponding author: Mohammed Ali Abdulrehman,** Materials Engineering Department, Faculty of Engineering, Mustansiriyah University, Baghdad, Iraq,
e-mail: mohammed_ali_mat@uomustansiriyah.edu.iq
Rusul Abdul Rahim Ghadban: Materials Engineering Department, Faculty of Engineering, Mustansiriyah University, Baghdad, Iraq,
e-mail: ebma010@uomustansiriyah.edu.iq

Table 1: Chemical composition analyses of slag

Oxides	%Content
SiO_2	38.2
Fe_2O_3	1.9
Al_2O_3	14.5
CaO	37
Sulfide sulfur	0.38
Cr_2O_5	0.02
TiO_2	0.8
MnO	3.1
MgO	8.1

slag is shown in Table 1, and other physical properties have been clarified in Table 2. Material requirements comply with ASTM C989 [10].

2.1.2 NaOH

NaOH is widely available in flake form and of high purity (more than 98%) is dissolved in water according to ASTM E291 [11].

2.1.3 Sodium silicate

The sodium silicate used in this study is imported from the United Arab Emirates and is widely available in the Iraqi market.

2.1.4 Coarse aggregate

Traditional gravel was utilized as coarse aggregate from Al-Nabai zone to make the mixtures for this study. The results of the examination showed their conformity with IQS 45/1984 [12].

2.1.5 Fine aggregate

Traditional sand used as fine aggregate is obtained from the Ekhedir region. The results of chemical and physical tests for the fine aggregate showed that it complies with the requirements of IQS No. 45/1984 [12].

Table 2: Slag physical characteristics

Characteristics	Outcomes
Surface area (cm^2/g)	5,338
Nature of material	Powder
Specific weight	3.2
Color	Light grey

Table 3: Characteristics of plasticizer

Technical properties	Descriptions
Color	Dark brownish liquid
Basis	Naphthalene formaldehyde sulfonate
Density (kg/L)	1.181 ± 0.01 @ 20°C
pH value	7–11
Chloride content	Nil

2.1.6 High range super plasticizer admixture (HRSPA)

Naphthalene formaldehyde plasticizer was used to improve workability and was in compliance with ASTM C494. Table 3 shows the properties of plasticizer.

2.1.7 Additional water

Tap water was utilized as additional water for colored geopolymer concrete and is suitable for concrete mix.

2.1.8 Pigments

Two types of pigments (in the form of powder) were utilized in this study (green Cr_2O_3 and yellow FeOOH) and wereimported from China in different proportions (0, 1, 2, 3) by weight % of the amount of slag in the mixes. Table 4 shows the surface area value of the pigments that was utilized in this study.

2.2 Mixtures of geopolymer concrete with different pigments

The colored geopolymer concrete mixtures are shown in Tables 5 and 6.

Table 4: Surface area value of pigments

Pigment	Fineness
Green Cr_2O_3	8,178 (cm^2/g)
Yellow FeOOH	12,720 (cm^2/g)

Table 5: Colored geopolymer concrete mixes*

Mixes	Slag (kg)	The alkaline solution (kg)	Added water (kg)
So	18	6.3	3.6
SG1	17.82	6.3	3.6
SG2	17.64	6.3	3.6
SG3	17.46	6.3	3.6
SY1	17.82	6.3	3.6
SY2	17.64	6.3	3.6
SY3	17.46	6.3	3.6

*Note: So, without pigments; SG, with green chromium oxide; and SY, geopolymer concrete with yellow iron oxide hydroxide.

2.3 Prepare alkaline solutions of geopolymer concrete mixes

2.3.1 Preparing of NaOH solution

To obtain 1 kg of a solution of NaOH at a concentration of 10 M, 314 g of NaOH is dissolved in 686 g of water [13].

2.3.2 Preparation of alkaline liquids for mixtures

The NaOH solution was mixed with the sodium silicate solution in a ratio of 1:2.5 for the purpose of preparing the alkaline liquid, taking into account the prior preparation of the solution (24 h before mixing the components of the mixture) [14].

2.4 Colored geopolymer concrete mixing procedure

Start by mixing the dry ingredients (pigments, slag, coarse aggregate, and fine aggregate) for 2–3 min using an electric mixer (200 L capacity), then add the prepared alkaline liquid, plasticizer, and additional water and mix them all for 4–5 min [14,15].

Table 6: Mixtures colored geopolymer concrete

Coarse aggregate (kg)	Fine aggregate (kg)	Pigment (kg)	HRSPA wt% of slag	Na_2SiO_3/NaOH
54	26.47	0	2	1:2.5
54	26.47	180	2	1:2.5
54	26.47	360	2	1:2.5
54	26.47	540	2	1:2.5
54	26.47	180	2	1:2.5
54	26.47	360	2	1:2.5
54	26.47	540	2	1:2.5

2.5 Curing

The curing process was carried out by placing the samples after extracting them from the mold in the open air at a temperature of 25–30°C for 28 days.

2.6 Tests of colored geopolymer concrete

2.6.1 Slump test

A slump test was performed on geopolymer concrete to determine the workability of the colored geopolymer concrete when it was in new condition. ASTM C143 [16] was used during testing as shown in Figure 1.

The slump test results of geopolymer concrete samples are presented in Table 7.

It is clear from Table 7 that the slump values decrease when the percentage of pigments increases, because the surface area of the pigments used in this research is higher than the surface area of the slag, and this property helps the pigment to attract water molecules more than the slag and thus reduce its workability.

Figure 1: Slump test.

Table 7: Slump values for samples of geopolymer concrete mixtures

Mixes	Slump (mm)
So	215
SG1	199
SG2	175
SG3	151
SY1	182
SY2	144
SY3	118

2.6.2 Compressive strength (fc)

This test was carried out in accordance with BS1881: Part 116:1989 [17]. Three cubic samples with dimensions of $100 \times 100 \times 100\,mm^3$ from each mixture and its average was calculated. The samples were tested after 28 days with a hydraulic machine with a capacity of 2,000 kN, as shown in Figure 2.

The results of the compressive strength of geopolymer concrete samples are presented in Table 8.

Pigments were added in the proportions of 0, 1, 2, and 3% for green and yellow. The addition of pigment (1%) gave the highest value in compressive strength of geopolymer concrete with both pigments, but when more than 1% of pigment was added, the value of compressive strength began to decrease gradually. The above behavior can be explained as follows:

- Adding pigment (green and yellow) to geopolymer concrete reduces the interaction of water with slag because the pigment has a higher surface area than slag and therefore tends to attract water molecules more than slag and this helps in obtaining greater compressive strength because the increase in water molecules interacting with the binder lead to a decrease in the bonding between the molecules of the bonding material [18].
- The addition of pigment can contribute to filling the voids in the geopolymer concrete, but an increase in the percentage of adding pigment can lead to the agglomeration of the pigment and formation of

Figure 2: Compressive strength test.

Figure 3: Flexural strength test.

Table 8: Compressive strength for samples of geopolymer concrete mixtures

Mixes	Compressive strength (N/mm^2)
So	32.6
SG1	33.5
SG2	32.1
SG3	30.9
SY1	33.2
SY2	32.8
SY3	31.6

Table 9: Flexural strength for colored geopolymer mixes

Mixes	Flexural strength (MPa)
So	6.06
SG1	6.32
SG2	6.33
SG3	6.04
SY1	6.41
SY2	6.12
SY3	5.83

segregation areas, and the segregation area in turn weakens the geopolymer concrete [19].

2.6.3 Flexural strength (fr)

This test was carried out according to the ASTM C78. Three prisms of each mixture were tested with dimensions of 100 × 100 × 500 mm^3. A hydraulic test machine with a capacity of 300 kN was used, as shown in Figure 3 [20].

The fr can be calculated by the following equation:

$$\mathrm{fr} = PL/bd^2, \qquad (1)$$

where fr is the flexural strength (MPa), P is the greatest load that causes the specimen to break (N), d is the dimension of prism depth (mm), L is the dimension of the span length (mm), and b is the dimension of prism base (mm).

Table 9 shows the results of tests for flexural strength.

It has been observed from Table 9 that the best value of flexural strength is at 1 and 2% for the green color and at 1% for the yellow color. When the percentage of addition increases, it causes a decrease in the value of the flexural strength. It is possible to adopt the same interpretations of the compressive strength on the flexural strength test.

Figure 4: The permeability test.

Table 10: Permeability test outcomes for colored geopolymer concrete

Mixes	Permeability (mm)
So	32
SG1	29
SG2	25
SG3	20
SY1	26
SY2	20
SY3	13

2.6.4 Permeability test

The amount of water entering the concrete member due to water pressure is defined by permeability. The permeability or water depth was tested according to BS 12390-8 [21] by setting the water pressure to 5 bar for 72 h as shown in Figure 4.

Table 10 shows the results of the permeability test.

It was noted from Table 10 that there is a decrease in the values of permeability with the increase in the percentage of pigment and this is due to the fact that the pigment has a role in filling the voids in the geopolymer concrete due to the fact that its surface area is higher than the surface area of the slag, and its high surface area plays a role in attracting water molecules more than the slag.

3 Conclusion

In the slump test, the workability values decrease with the increase in the percentage of pigment while in the compressive strength test, the highest values were obtained when adding 1% of the pigment to both colors, where there was an increase from the reference value by 2.7 and 1.8% for green and yellow, respectively. In the flexural strength test, the best values were obtained when 1 and 2% were added to the green color, where there was an increase of 4.4% over the reference value, while in the yellow color, the highest value was obtained when 1% was added, where there was an increase of 5.7% from the reference value. When you continue adding pigment in both of the above tests, the results begin to deteriorate. As for the permeability test, the value of the permeability decreases with the increase of the added pigment.

In general, we do not recommend that the percentage of adding pigment be higher than 1%.

Acknowledgments: The authors would like to thank Mustansiriyah University (www.uomustansiriyah.edu.iq) Baghdad-Iraq for its support in the present work.

Funding information: The authors state no funding involved.

Author contributions: All authors have accepted responsibility for the entire content of this manuscript and approved its submission.

Conflict of interest: The authors state no conflict of interest.

Reference

[1] Mohammed ZA. Structural behavior of fiber reinforced geopolymer concrete beams under static and repeated loading [dissertation]. Baghdad, Iraq: Civil Engineering Department, Mustansiriyah University; 2020.
[2] Hardjito DS, Wallah DM, Sumajouw J, Rangan BV. The development of fly ash-based geopolymer concrete. Mater J. 2004;101(6):467–72.
[3] Bernal SA, Ruby MG, Alba LP, John LP, Erich DR, Silvio D. Effect of binder content on the performance of alkali-activated slag concretes. Cem Concr Res. 2011;41(1):1–8.
[4] Srinivasan K, Syed AA, Gogul A, Chevvell KE. Characteristics study on mechanical properties of slag based geopolymer concret. Int Res J Eng Technol (IRJET). 2016;3(5):1984–8.
[5] Türkmen I, Karakoç MB, Kantarci FK, Ekincì E. Effect of NaOH concentrations and curing temperatures on mechanical properties of geopolymer pastes produced from fly ash and Elaziğ ferrochrome slag. Int J Mech Prod Eng (IJMPE). 2021;9(12):97–9.
[6] Allan JD. A manufacturer's opinion on the cause or effect on colouring concrete. Proceedings of the 2nd International workshop on Concrete Block Paving; 1994; Oslo, Norway; p. 330–343.
[7] Lee HS, Lee JY, Yu MY. Influence of iron oxide pigments on the properties of concrete interlocking blocks. Cem Concr Res. 2003;33(11):1889–96.
[8] Karaguler M, Sungur S. The effect of using pigment additive in architectural self-compacting concrete. Proceedings of the 7th International Workshop of Concrete, the Development in Concrete Technology and Application; 2007 Nov 28–30; Istanbul, Turkey; p. 55–64.
[9] Mahmud MH, Abdulrehman MA. Studying some of the mechanical and physical properties of colored geopolymer concrete. J Eng Sustain Dev (JEASD). 2021;1((Special Issue)):49–59.
[10] American Standard for Testing Materials C989/C989M. Standard Specification for Slag Cement for Use in Concrete and Mortars; 2012.
[11] American Standard for Testing Materials E291. Standard Test Methods for Chemical Analysis of Caustic Soda and Caustic Potash (Sodium Hydroxide and Potassium Hydroxide); 2009.
[12] Iraqi Specification IQS No.45. Aggregate from natural sources for concrete and construction. Iraqi Specification Central Agency for Standardization and Quality Control. Baghdad: 1984.

[13] Hardjito D, Rangan BV. Development and properties of low-calcium fly ash-based geopolymer concrete. Perth, Australia: Curtin University of Technology; 2005.
[14] Lloyd N, Rangan V. Geopolymer concrete with fly ash. Proceedings of the Second International Conference on sustainable construction Materials and Technologies. UWM Center for By-Products Utilization; 2010 Jun 28–30; Ancona, Itay.
[15] Sanni SH, Khadiranaikar R. Performance of alkaline solutions on grades of geopolymer concrete. Int J Res Eng Technol. 2013;2(11):366–71.
[16] American Standard for Testing Materials ASTM C143/C143M. Standard Test Method for Slump of Hydraulic-Cement Concrete; 2010.
[17] British Standards Institution 1881, Part 116. Method of Determination of Compressive Strength of Concrete Cubes; 1989.
[18] Al-Kharabsheh B. An experimental study on colored concrete using pigments from raw local materials. Proceedings of TCMB 3rd International Symposium. 2007 May 21–23. Istanbul, Turkey; Vol. 2, p. 875–882.
[19] Hospodarova V, Junak J, Stevulova N. Color pigments in concrete and their properties. Pollack Periodica. 2015;10(3):143–51.
[20] American Standard for Testing Materials ASTM C78. Standard Test Method for Flexural Strength of Concrete; 2005.
[21] British Standard EN 12390, Part 8. Testing hardened concrete “Depth of penetration of water under pressure”; 2009.